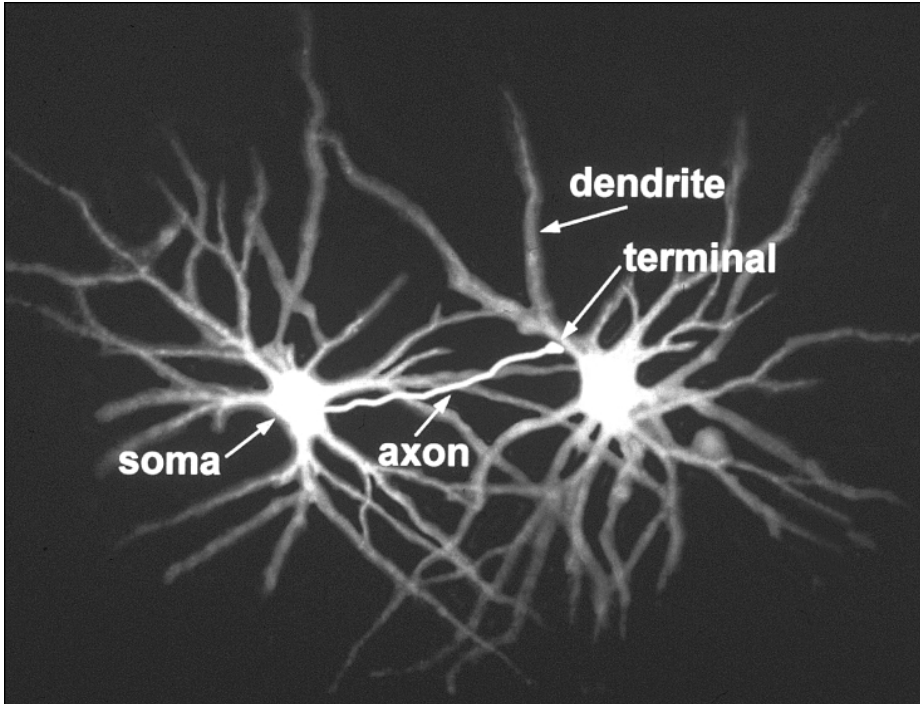


Lesson 2

Explore/ Explain

Neurons, Brain Chemistry, and Neurotransmission



Source: National Institute on Drug Abuse (1996) The Brain & the Actions of Cocaine, Opiates, and Marijuana. Slide Teaching Packet for Scientists.

Overview

Students learn that the neuron is the functional unit of the brain. To learn how neurons convey information, students analyze a sequence of illustrations and watch an animation. They see that neurons communicate using electrical signals and chemical messengers called neurotransmitters that either stimulate or inhibit the activity of a responding neuron. Students then use the information they have gained to deduce how one neuron influences the action of another.

Major Concept

Neurons convey information using electrical and chemical signals.

Objectives

By the end of these activities, the students will

- understand the hierarchical organization of the brain, neuron, and synapse;
- understand the sequence of events involved in communication at the synapse; and
- understand that synaptic transmission involves neurotransmitters that may be either excitatory or inhibitory.

At a Glance

The Brain: Understanding Neurobiology Through the Study of Addiction

Basic Science–Health Connection

Communication between neurons is the foundation for brain function. Understanding how neurotransmission occurs is crucial to understanding how the brain processes and integrates information. Interruption of neural communication causes changes in cognitive processes and behavior.

Background Information

The Brain Is Made Up of Nerve Cells and Glial Cells

The brain of an adult human weighs about three pounds and contains billions of cells. The two distinct classes of cells in the nervous system are **neurons** (nerve cells) and **glia** (glial cells).

The basic signaling unit of the nervous system is the neuron. The brain contains billions of neurons; the best estimates are that the adult human brain contains 10^{11} neurons. The interactions between neurons enable people to think, move, maintain homeostasis, and feel emotions. A neuron is a specialized cell that can produce different actions because of its precise connections with other neurons, sensory receptors, and muscle cells. A typical neuron has four morphologically defined regions: the cell body, dendrites, axons, and presynaptic terminals.^{1, 2, 3}

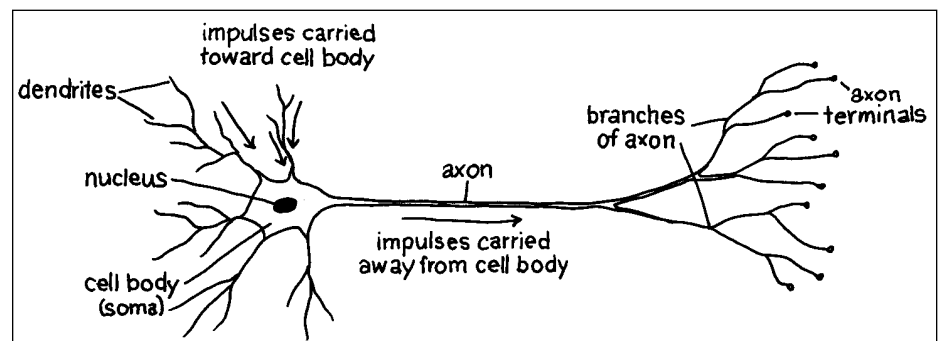


Figure 2.1: The neuron, or nerve cell, is the functional unit of the nervous system. The neuron has processes called dendrites that receive signals and an axon that transmits signals to another neuron.

The **cell body**, also called the **soma**, is the metabolic center of the neuron. The nucleus is located in the cell body and most of the cell's protein synthesis occurs in the cell body.

A neuron usually has multiple processes, or fibers, called **dendrites** that extend from the cell body. These processes usually branch out somewhat like tree branches and serve as the main apparatus for receiving input into the neuron from other nerve cells.

The cell body also gives rise to the **axon**. Axons can be very long processes; in some cases, they may be up to one meter in length. The axon is the part of the neuron that is specialized to carry messages away from the cell body and to relay messages to other cells. Some large axons are surrounded by a fatty insulating material called myelin, which enables the electrical signals to travel down the axon at higher speeds.

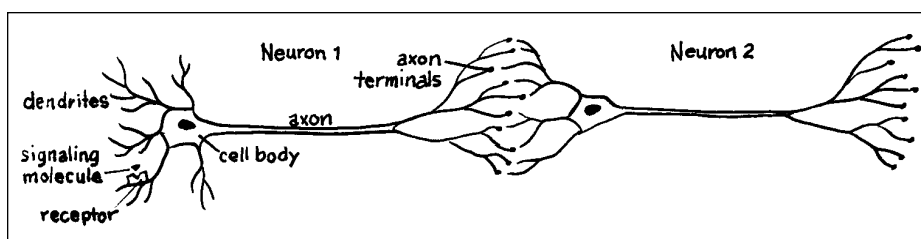


Figure 2.2: Neurons transmit information to other neurons. Information passes from the axon of the presynaptic neuron to the dendrites of the postsynaptic neuron.

Near its end, the axon divides into many fine branches that have specialized swellings called presynaptic terminals. These presynaptic terminals end in close proximity to the dendrites of another neuron. The dendrite of one neuron receives the message sent from the presynaptic terminal of another neuron.

The site where a presynaptic terminal ends in close proximity to a receiving dendrite is called the **synapse**. The cell that sends out information is called the **presynaptic** neuron, and the cell that receives the information is called the **postsynaptic** neuron. It is important to note that the synapse is *not* a physical connection between the two neurons; there is no cytoplasmic continuity between the two neurons. The intercellular space between the presynaptic and postsynaptic neurons is called the **synaptic space** or **synaptic cleft**. An average neuron forms approximately 1,000 synapses with other neurons. It has been estimated that there are more synapses in the human brain than there are stars in our galaxy. Furthermore, synaptic connections are not static. Neurons form new synapses or strengthen synaptic connections in response to life experiences. This dynamic change in neuronal connections is the basis of learning.

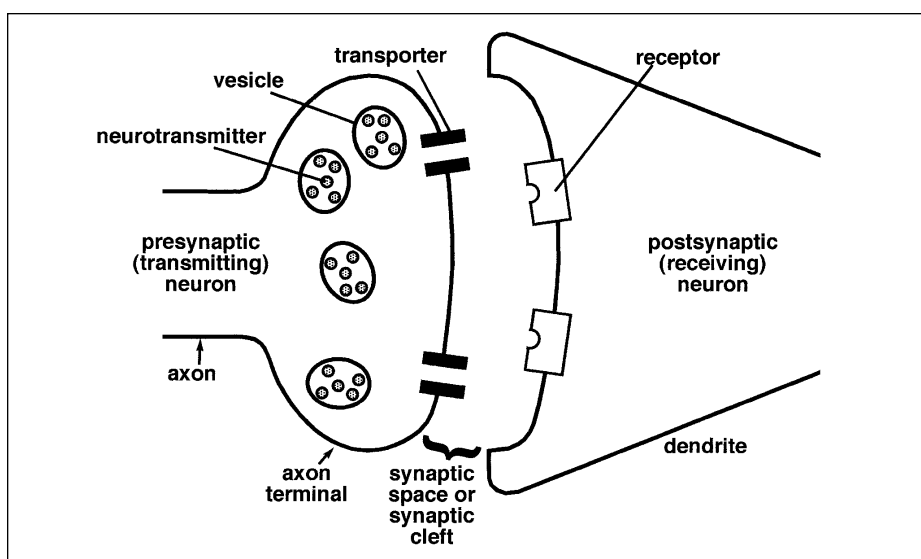


Figure 2.3: The synapse is the site where chemical signals pass between neurons. Neurotransmitter is released from the presynaptic neuron terminals into the extracellular space, the synaptic cleft or synaptic space. The released neurotransmitter molecules can then bind to specific receptors on the postsynaptic neuron membrane to elicit a response.

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The brain contains another class of cells called glia. There are as many as ten to fifty times more glial cells than neurons in the central nervous system. Glial cells are categorized as microglia or macroglia. Microglia are phagocytic cells that are mobilized after injury, infection or disease. They are derived from macrophages and are unrelated to other cell types in the nervous system. The three types of macroglia are oligodendrocytes, astrocytes, and Schwann cells. The oligodendrocytes and Schwann cells form the myelin sheaths that insulate axons and enhance conduction of electrical signals along the axons.

Scientists know less about the functions of glial cells than they do about the functions of neurons. Glial cells fulfill a variety of functions including:

- Glial cells function as supporting elements in the nervous system to provide structure and to separate and insulate groups of neurons.
- Oligodendrocytes in the central nervous system and Schwann cells in the peripheral nervous system form myelin, the sheath that wraps around certain axons.
- Some glial cells are scavengers that remove debris after injury or neuronal death.
- Some glial cells buffer the potassium ion (K^+) concentration in the extracellular space, and some glial cells take up and remove chemical neurotransmitters from the extracellular space after synaptic transmission.
- Some glial cells guide the migration of neurons and direct the outgrowth of axons during development.
- Some glial cells induce formation of impermeable tight junctions in endothelial cells that line the capillaries and venules of the brain to form the blood-brain barrier.
- Glial cells may serve nutritive functions for nerve cells.³

The Blood-Brain Barrier

The blood-brain barrier protects the neurons and glial cells in the brain from substances that could harm the cells. Endothelial cells that form the capillaries and venules make this barrier forming impermeable tight junctions. Astrocytes surround the endothelial cells and induce them to form these junctions. Unlike blood vessels in other parts of the body that are relatively leaky to a variety of molecules, the blood-brain barrier keeps many substances, including toxins, away from the neurons and glia.

Blood gases, such as oxygen, and small nutritional molecules do get into the brain.^{3,4} In addition, drugs of abuse can penetrate the blood-brain barrier. Because most drugs are fat-soluble they can pass through the barrier to reach the brain cells.

The blood-brain barrier is important for maintaining the environment of neurons in the brain, but it also presents problems for scientists who are investigating new treatments for brain disorders. If a medication cannot get into the brain to the neurons, it cannot be effective. Researchers attempt to circumvent the problems in different ways. Some techniques attach potential therapeutic agents to molecules that pass through the blood-brain barrier while others attempt to open the blood-brain barrier so that the therapeutic compounds can reach the brain's neurons.⁵

Neurons Use Electrical and Chemical Signals to Transmit Information

The billions of neurons that make up the brain coordinate thought, behavior, homeostasis, and more. How do all these neurons pass and receive information?

Neurons convey information by transmitting messages to other neurons or other types of cells, such as muscles. The following discussion focuses on how one neuron communicates with another neuron. Neurons employ electrical signals to relay information from one part of the neuron to another. The neuron converts the electrical signal to a chemical signal in order to pass the information to another neuron. The target neuron then converts the message back to an electrical impulse to continue the process.

Within a single neuron, information is conducted via electrical signaling. When a neuron is stimulated, an electrical impulse, called an **action potential**, moves along the neuron axon or dendrite.⁶ Action potentials enable signals to travel very rapidly along the neuron fiber. Action potentials last less than 2 milliseconds (1 millisecond = 0.001 second) and the fastest action potentials can travel the length of a football field in one second. Action potentials result from the flow of ions across the neuronal cell membrane. Neurons, like all cells, maintain a balance of ions inside the cell that differs from the balance outside of the cell. This uneven distribution of ions creates an electrical potential across the cell membrane. This is called the **resting membrane potential**. In humans, the resting membrane potential ranges from -40 millivolts (mV) to -80 mV with -65 mV as an average resting membrane potential. The resting membrane potential is, by convention, assigned a negative number because the inside of the neuron is more negatively charged than the outside environment of the neuron. This negative charge results from the unequal distribution of sodium ions (Na^+), potassium ions (K^+), chloride ions (Cl^-), and other organic ions. The resting membrane potential is maintained by an energy-dependent Na^+ - K^+ pump that keeps Na^+ levels low inside the neuron and K^+ levels high inside the neuron. In addition, the neuronal membrane is more permeable to K^+ than it is to Na^+ , so that K^+ tends to leak out of the cell more readily than Na^+ diffuses into the cell.

A stimulus occurring at the end of a nerve fiber starts an electrical change that travels like a wave over the length of the neuron. This electrical change, the action potential, results from a change in the permeability of the neuronal membrane. Sodium ions rush into the neuron, and the inside of the cell becomes more positive. The Na^+ - K^+ pump then restores the balance of sodium and potassium to resting levels. However, the influx of Na^+ ions in one area of the neuron fiber starts a similar change in the adjoining segment and the impulse moves from one end of the neuronal fiber to the other. Action potentials are an **all-or-none phenomenon**. Regardless of the stimuli, the amplitude and duration of an action potential are the same. The action potential either occurs or it doesn't. The response of the neuron to an action potential depends on how many action potentials it transmits and the time interval between them.

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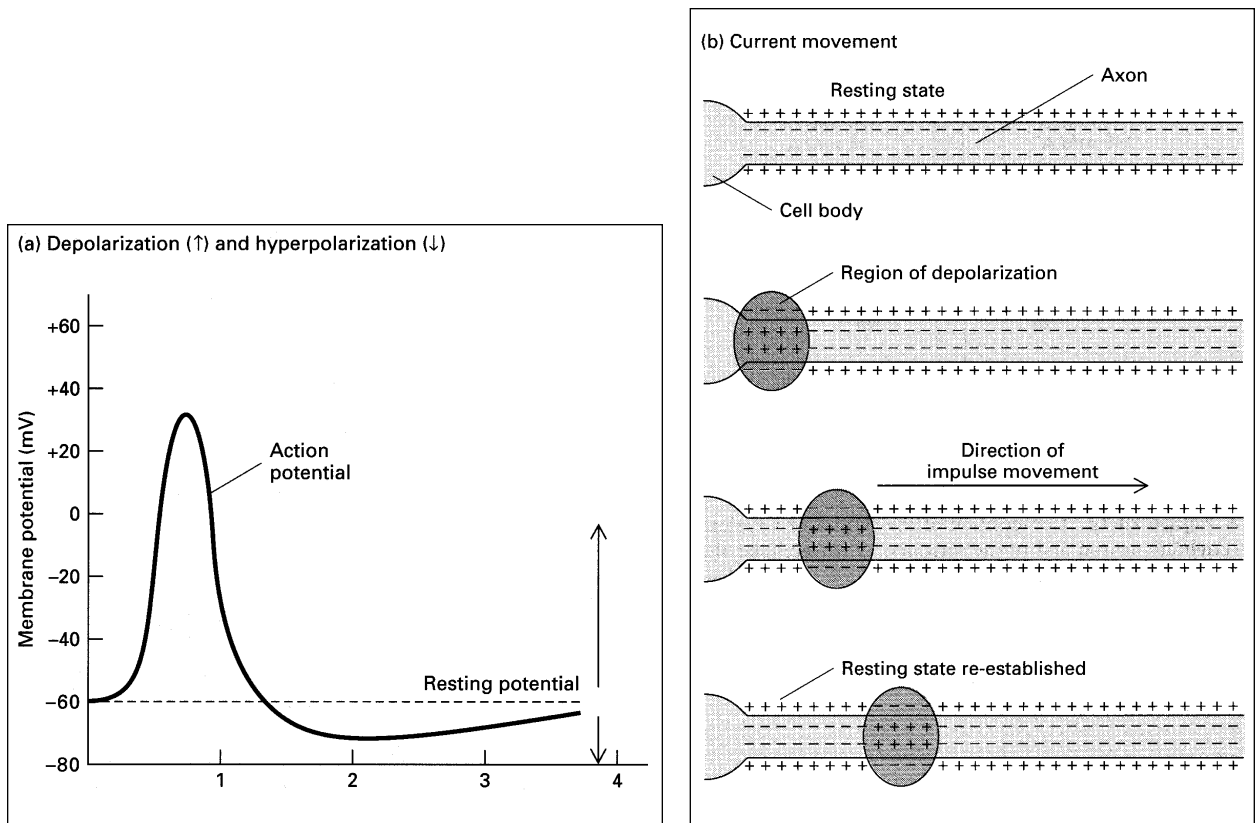


Figure 2.4: (a) Recording of an action potential in an axon following stimulation at time 0 due to changes in the permeability of the cell membrane to sodium and potassium ions. (b) The cell membrane of a resting neuron is more negative on the inside of the cell than on the outside. When the neuron is stimulated, the permeability of the membrane changes allowing Na^+ to rush into the cell. This causes the inside of the cell to become more positive. This local change starts a similar change in the adjoining segment of the neuron's membrane. In this manner, the electrical impulse moves along the neuron. From: Molecular Cell Biology by Lodish et al. 1986, 1990 by Scientific American Books, Inc. Used with permission by W.H. Freeman and Company.

Electrical signals carry information *within* a single neuron. Communication *between* neurons (with a few exceptions in mammals) is a chemical process. When the neuron is stimulated, the electrical signal (action potential) travels down the axon to the axon terminals. When the electrical signal reaches the end of the axon, it triggers a series of chemical changes in the neuron. Calcium ions (Ca^{++}) flow into the neuron. The increased Ca^{++} in the axon terminal then initiates the release of neurotransmitter. A **neurotransmitter** is a molecule that is released from a neuron to relay information to another cell. Neurotransmitter molecules are stored in membranous sacs called **vesicles** in the axon terminal. Each vesicle contains thousands of molecules of a neurotransmitter. For neurons to release their neurotransmitter, the vesicles fuse with the neuronal membrane and then release their contents, the neurotransmitter, via exocytosis. The neurotransmitter molecules are released into the synaptic space and diffuse across the synaptic space to the postsynaptic neuron. A neurotransmitter molecule can then bind to a special receptor on the membrane of the postsynaptic neuron. **Receptors** are membrane proteins that

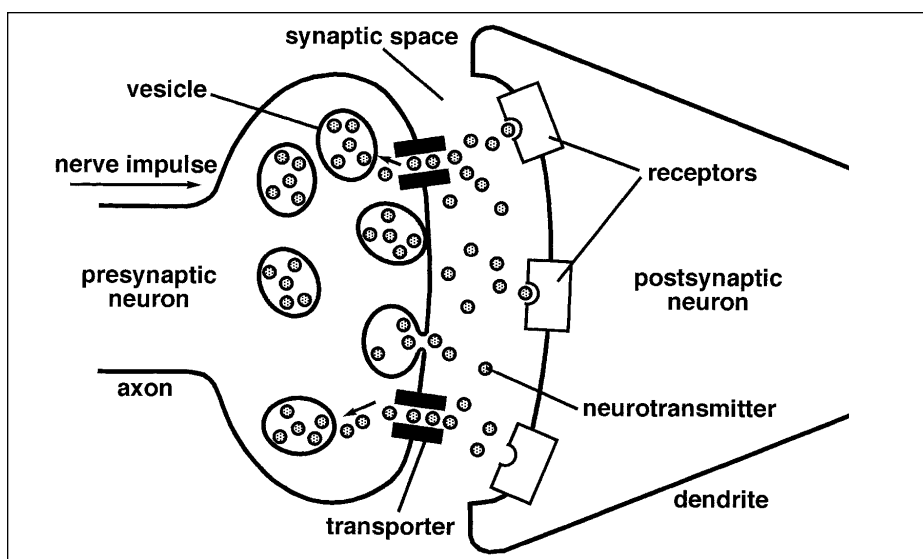


Figure 2.5: Schematic diagram of a synapse. In response to an electrical impulse, neurotransmitter molecules released from the presynaptic axon terminal bind to the specific receptors for that neurotransmitter on the postsynaptic neuron. After binding to the receptor, the neurotransmitter molecules either may be taken back up into the presynaptic neuron through the transporter molecules for repackaging into vesicles or may be degraded by enzymes present in the synaptic cleft.

are able to bind a specific chemical substance, such as a neurotransmitter. For example, the dopamine receptor binds the neurotransmitter dopamine, but does not bind other neurotransmitters such as serotonin. The interaction of a receptor and neurotransmitter can be thought of as a lock-and-key for regulating neuronal function. Just as a key fits only a specific lock, a neurotransmitter binds only to a specific receptor. The chemical binding of neurotransmitter and receptor initiates changes in the postsynaptic neuron that may generate an action potential in the postsynaptic neuron. If it does trigger an action potential, the communication process continues. After a neurotransmitter molecule binds to its receptor on the postsynaptic neuron, it comes off of (releases from) the receptor and diffuses back into the synaptic space. The released neurotransmitter, as well as any neurotransmitter that did not bind to a receptor, is either degraded by enzymes in the synaptic cleft or it may be

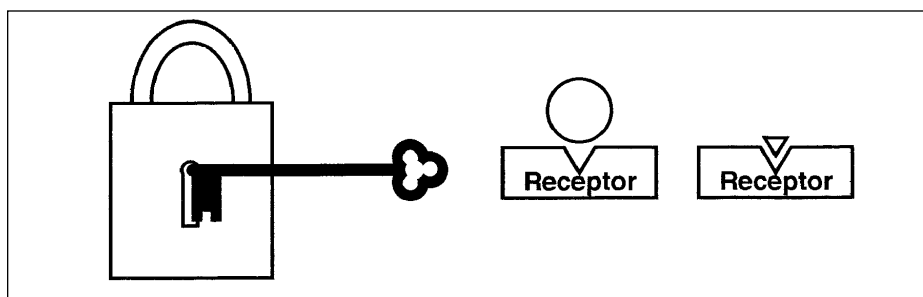


Figure 2.6: Like a lock that will open only if the right key is used, a receptor will bind only a molecule that has the right chemical shape. Molecules that do not have the right “fit” will not bind to the receptor and will not cause a response.

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taken back up into the presynaptic axon terminal by active transport through a **transporter** or **reuptake pump**. Once the neurotransmitter is back inside the axon terminal, it is either destroyed or repackaged into new vesicles that may be released the next time the neuron is stimulated. Different neurotransmitters are inactivated in different ways.

Neurotransmitters Can Be Excitatory or Inhibitory

Different neurotransmitters fulfill different functions in the brain. Some neurotransmitters act to stimulate the firing of a postsynaptic neuron. Neurotransmitters that act this way are called **excitatory** neurotransmitters because they lead to changes that generate an action potential in the responding neuron.^{1,7} Other neurotransmitters, called **inhibitory** neurotransmitters, tend to block the changes that cause an action potential to be generated in the responding cell. Table 2.1 lists some of the major neurotransmitters used in the body and their major functions. Each neuron generally synthesizes and releases a single type of neurotransmitter. (Neurons may contain other signaling chemicals, such as neurohormones, in addition to their neurotransmitter.)

The postsynaptic neuron often receives both excitatory and inhibitory messages. The response of the postsynaptic cell depends on which message is stronger. Keep in mind that a single neurotransmitter molecule cannot cause an action potential in the responding neuron. An action potential occurs when many neurotransmitter molecules bind to and activate their receptors. Each interaction contributes to the membrane permeability changes that generate the resultant action potential.

Table 2.1: Major Neurotransmitters in the Body^{1, 7, 8}

Neurotransmitter	Role in the body
Acetylcholine	A neurotransmitter used by spinal cord neurons to control muscles and by many neurons in the brain to regulate memory. In most instances, acetylcholine is excitatory.
Dopamine	The neurotransmitter that produces feelings of pleasure when released by the brain reward system. Dopamine has multiple functions depending on where in the brain it acts. It is usually inhibitory.
GABA (gamma-aminobutyric acid)	The major inhibitory neurotransmitter in the brain.
Glutamate	The most common excitatory neurotransmitter in the brain.
Glycine	A neurotransmitter used mainly by neurons in the spinal cord. It probably always acts as an inhibitory neurotransmitter.
Norepinephrine	Norepinephrine acts as a neurotransmitter and a hormone. In the peripheral nervous system, it is part of the fight-or-flight response. In the brain, it acts as a neurotransmitter regulating normal brain processes. Norepinephrine is usually excitatory, but is inhibitory in a few brain areas.
Serotonin	A neurotransmitter involved in many functions including mood, appetite, and sensory perception. In the spinal cord, serotonin is inhibitory in pain pathways.

CD-ROM Activities	
Activity Number	CD-ROM
Activity 1	no
Activity 2	yes
Activity 3	yes
Activity 4	optional

Photocopies		
For the class	For each group of 3 students	For each student
1 transparency of Master 2.1, <i>Anatomy of a Neuron</i> 1 transparency of Master 2.2, <i>Neurons Interact with Other Neurons Through Synapses</i> 1 transparency of Master 2.4, <i>Neurons Communicate by Neurotransmission</i> 1 transparency of Master 2.6, <i>Recording the Activity of a Neuron</i> 1 transparency of Master 1.7, <i>The Reward System</i> (from Lesson 1)	1 copy of Master 2.3, <i>How Do Neurons Communicate?</i>	1 copy of Master 2.5, <i>Neurotransmission</i> 1 copy of Master 2.7, <i>Neurotransmitter Actions</i> 1 copy of Master 2.8, <i>Neurons in Series</i>

Materials	
Activity 1	overhead projector
Activity 2	overhead projector (if using the version without the CD-ROM)
Activity 3	none
Activity 4	none

Preparation

Arrange for students to have access to computers for Activities 2, 3, and 4.

ACTIVITY 1: ANATOMY OF A NEURON

1. Remind students of the PET scans they examined in Activity 2 of Lesson 1.

Ask students to think about the areas shown in red or yellow on a PET scan in response to a stimulus. What specifically composes those areas?

Students may respond correctly that the areas shown in red or yellow on the PET images are made up of *brain cells* that are more active than the cells

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Content Standard C:
Cells have particular structures that underlie their functions.

Content Standard C:
Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells.

in other regions. Students may even be able to say that the areas represent *neurons* in the brain that are activated. The goal is to reinforce that the brain is made up of millions of individual cells. The areas shown in the PET images are not just large amorphous masses.

- 2. Display a transparency of Master 2.1, *Anatomy of a Neuron*. Explain to students that the basic functional unit of the brain and nervous system is the neuron. Point out the parts of a neuron and discuss their functions.**

The cell body of the neuron is the metabolic center of the neuron. The nucleus is in the cell body. Most of the proteins are made in the cell body.

Neurons have specialized cell processes, or fibers, that extend from the cell body. The dendrites are branched fibrous processes specialized to receive input and carry information *toward* the cell body.

The axon is usually larger in diameter than the dendrites and is specialized to carry information *away* from the cell body. An axon may be very long. Some axons are over one meter in length.

- 3. Display the top half of a transparency of Master 2.2, *Neurons Interact With Other Neurons Through Synapses*. Point out that the axon terminals of one neuron end near the dendrites of another neuron.**
- 4. Reveal the lower portion of Master 2.2 showing the synapse. Inform students that the connection between the two neurons is called a *synapse*. Explain the terms *presynaptic* and *postsynaptic*.**

The *presynaptic* neuron is the neuron whose axon forms a synapse with the dendrite of another neuron. The presynaptic neuron sends out information.

The *postsynaptic* neuron is the neuron whose dendrite forms a synapse with the axon of the presynaptic neuron. The postsynaptic neuron receives information.

Note: Help students understand that there is no *physical* connection between the two neurons.

- 5. When students understand that the brain is composed of neurons and neurons interact with other neurons, display the transparency of Master 1.7, *The Reward System* (used in Lesson 1), again and discuss the reward pathway in terms of the neurons.**

The cell bodies of the neurons that drugs affect are located in the ventral tegmental area (VTA). Those cells extend their axons to nerve cells in an area of the brain called the nucleus accumbens. Some nerve fibers extend to part of the frontal region of the cerebral cortex.

ACTIVITY 2: HOW DO NEURONS COMMUNICATE?

Before doing this activity, students need to have a good understanding of the difference between an axon and a dendrite and the direction of information flow along these neuronal fibers. Remember that dendrites carry information toward the cell body and axons carry information away from the cell body. Also, students need to understand the terms presynaptic and postsynaptic.

In this activity, students will use the CD-ROM to enhance what they deduce from a print-based activity. If computers are not available for viewing the CD-ROM, a print modification of the activity is also provided. The procedures for each version of the activity are the same except for Step #4. When you reach that point in the activity, select the appropriate step.

1. Ask students to consider what purpose synapses serve.

Some students are likely to respond correctly that synapses serve to connect neurons (synapses do not connect neurons physically, but they do connect them functionally). This enables neurons to communicate by passing signals between them.

2. Remind students that the brain is an organ that regulates body functions, behaviors, and emotions. Neurons are the cells that fulfill these functions. How do neurons do this?

Neurons control these functions by passing signals across the synapse from one neuron to the next that dictate whether the receiving neuron is activated.

3. Divide the class into groups of three students. Give each group a copy of Master 2.3, *How Do Neurons Communicate?* Ask students to look at and discuss the diagrams and, as a group, write a summary of how they believe the neurons are interacting at each step.

At this point, students will not know the correct terminology for the structures and molecules involved in neurotransmission. Encourage students to use whatever terms they wish to describe what is represented in the diagrams. The main point of this activity is for students to begin to understand that specific events happen both within a neuron and between neurons during neurotransmission.

SAMPLE ANSWERS TO MASTER 2.3

Students are likely to use a variety of terms in their responses. Although at this point the use of correct vocabulary is not the critical issue, some students will use the terms axon, dendrite, presynaptic, and postsynaptic that they learned in Activity 1.

Diagram #1 The presynaptic neuron ending has large circles in it. The large circles have smaller circles inside. There are two sets of bars that cross the end (membrane) of the presynaptic neuron. The postsynaptic neuron has two rectangular-shaped boxes on the end (membrane) of the neuron.



Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.

Content Standard A: Communicate and defend a scientific argument.

Content Standard C: Cell functions are regulated.

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Diagram #2 Nothing has changed except that there is a lightning bolt (electrical signal) and an arrow indicating that the lightning bolt is moving toward the end of the presynaptic neuron.

Diagram #3 One of the larger circles is now in contact with the end of the presynaptic neuron. Another circle is now releasing the small circles into the space between the neurons.

Diagram #4 The small circles are in the space between the neurons and one small circle is now attached to the box-shaped figures on the end of the postsynaptic neuron.

Diagram #5 The lightning bolt symbol (electrical signal) is at the postsynaptic neuron now. The arrow indicates that it is moving away from the neuron ending.

Diagram #6 The small circles are no longer attached to the box-shaped figures on the postsynaptic neurons. The arrows seem to indicate that the small circles are now moving back into the presynaptic neuron and going back into the larger circles.

4. Have the students watch the neurotransmission animation on the CD-ROM. They may wish to view the animation several times.



Students can access the animation by clicking on *Neurons, Brain Chemistry, and Neurotransmission* on the main menu and then clicking on the button, *How Neurotransmission Works*.

Now that students have explored neurotransmission by completing Master 2.3, the animation will help them incorporate the proper terminology and clarify any misunderstandings.



If computers are not available to view the CD-ROM animation of neurotransmission, display a copy of Master 2.4, *Neurons Communicate by Neurotransmission*. Read through the material with the students.

Students should **not** copy the information on Master 2.4. The goal is for students to listen to the reading to help them learn the proper terminology and clarify their understanding of neurotransmission.

5. After the students have been introduced to the proper terminology by the animation or the reading, give each student a copy of Master 2.5, *Neurotransmission*. Ask them to revise their summary of neurotransmission using the appropriate terminology. Encourage students to discuss their answers with the other members of their group.

Students may wish to watch the animation or review the reading again while doing this step. The goal is not to have students copy the explanation from the CD-ROM, but to revise their understanding of neurotransmission, incorporate the appropriate terminology, and correct any misconceptions they had from Master 2.3.

SAMPLE ANSWERS TO MASTER 2.5

Diagram #1 This diagram shows the component parts of the neurotransmission process between electrical impulses.

Diagram #2 An electrical impulse travels down the axon toward the presynaptic nerve terminals.

Diagram #3 The vesicles containing neurotransmitter move toward the neuron cell membrane at the end of the axon. The vesicles fuse to the membrane and then release their contents (neurotransmitter molecules) into the synaptic cleft.

Diagram #4 The neurotransmitter is in the synaptic cleft and binds to the receptor on the postsynaptic neuron's membrane.

Diagram #5 Neurotransmitter molecules are still bound to the receptors and an electrical signal passes along the postsynaptic neuron away from the neuron's ending.

Diagram #6 Neurotransmitter molecules are released from the receptors. Neurotransmitter molecules are taken back up into the presynaptic neuron through the transporter. Once inside the presynaptic neuron terminal, the neurotransmitter molecules are repackaged into vesicles.

6. Once the groups have finished revising their summaries, hold a class discussion and put together a summary of how neurotransmission occurs. Inform students that the diagrams and CD-ROM animation are simplified models of neurotransmission. Many hundreds or thousands of receptors that can bind neurotransmitter are present in the dendrites of a postsynaptic neuron.

7. Remind students of the reward system. The neurons that make up the reward system use a neurotransmitter called *dopamine*. Dopamine neurotransmission occurs as the students learned in Masters 2.3, 2.4 (print alternative), 2.5, and the CD-ROM animation.

ACTIVITY 3: DO ALL NEUROTRANSMITTERS HAVE THE SAME EFFECT?

Now that students understand that neurotransmitters are the chemical messengers involved in communication between neurons, students will learn that different neurotransmitters can affect neurotransmission differently.

1. Show an overhead transparency of Master 2.6, *Recording the Activity of a Neuron*. Explain that scientists study the activity of neurons by recording the electrical impulses that neurons generate when they are activated, or fire. These electrical impulses are called action potentials.

Master 2.6 shows a diagram of a microelectrode recording the electrical activity of a neuron in the brain. The action potentials are amplified, and then analyzed by a computer that counts the number of spikes that occur during a period of time. The action potentials appear as vertical lines, or spikes, on the oscilloscope. If the recording were slowed down,



Content Standard C:
Cell functions are regulated.

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the action potentials would appear similar to that shown in Figure 2.4 (see Background Information section). A signal is also sent to an audio amplifier that produces a click sound each time an action potential is generated in the neuron. The more frequently the spikes appear on the screen with accompanying audible clicks, the more frequently the neuron is firing.

- 2. Divide the class into groups of three. Give each group a copy of Master 2.7, *Neurotransmitter Actions*. Tell students that they will analyze the effects of different neurotransmitters on the activity of a neuron. Have the groups answer the questions that follow the data analysis.**

After the groups have completed the questions, discuss their answers to make sure that students understand that different neurotransmitters have different effects on neurons.

SAMPLE ANSWERS TO MASTER 2.7

Question 1. Why is saline applied to the resting neuron?

The resting neuron is the control for the experiment. If a scientist wants to determine what effect applying a neurotransmitter has on a neuron, he or she must have a control. The neurotransmitter applied to the other neurons would be in a saline solution, so applying saline to the resting neuron provides information about how a neuron responds to the solvent solution. If the control neuron does not respond in the same way as the experimental neurons, this indicates that the neurotransmitter applied to those neurons is the cause for the response, not the saline itself, or the act of applying a solution to the neuron.

Question 2. When the neurotransmitter glutamate is applied to the neuron, how does its activity change?

Glutamate stimulates the neuron and causes it to generate more electrical impulses.

Question 3. How does the application of the two neurotransmitters, glutamate and GABA, change the activity of the neuron?

The application of glutamate and GABA to the neuron inhibits the neuron so that it generates few electrical impulses.

Question 4. Predict how the activity of the neuron would change if only GABA was applied to the neuron.

If GABA can inhibit a neuron even when glutamate is added, GABA by itself should inhibit the neuron's activity.

Question 5. Do all neurotransmitters affect a neuron in the same way?

No, the neurotransmitters glutamate and GABA have opposite effects on the neuron's activity.

Question 6. *How would the application of glutamate to a neuron change the amount of neurotransmitter that is released from that neuron? How would the application of GABA to a neuron change the amount of neurotransmitter that is released from that neuron?*

If glutamate is applied to a neuron, it causes the neuron to generate more electrical impulses. This would increase the amount of neurotransmitter that the neuron releases from its axon terminals.

If GABA is applied to a neuron, it reduces the number of electrical impulses generated by that neuron. The decreased activity in the neuron would decrease the amount of neurotransmitter that the neuron releases from its axon terminals.



3. Students can continue this activity using the CD-ROM simulation of applying neurotransmitters to a neuron.

From the main menu on the CD-ROM, click on *Neurons, Brain Chemistry, and Neurotransmission* and then select *Neurotransmitter Actions*.

ACTIVITY 4: ONE NEURON SIGNALS ANOTHER

This activity is the most challenging one in the lesson. It requires students to integrate what they learned in Activities 2 and 3. If students successfully complete this activity, they will have a good understanding of how neurons communicate.

- 1. Copy the chart from Master 2.8, *Neurons in Series*, onto the board.**
- 2. Now that students understand that neurotransmitters can either stimulate or inhibit the generation of action potentials in a neuron, they will continue to examine how one neuron signals another in a series. Give each student a copy of Master 2.8. As a class, work through Case A on the master to determine how the stimulatory and inhibitory neurotransmitter effects alter dopamine release from the last neuron in the series. Fill in the answers on the chart.**

You may wish to use an \uparrow or \downarrow arrow to indicate an increase or decrease in the activity of the neuron or the amount of neurotransmitter released from a neuron. Students may find it helpful to refer to their work on Master 2.5.



Content Standard A:

Formulate and revise scientific explanations and models using logic and evidence.

Content Standard A:

Communicate and defend a scientific argument.

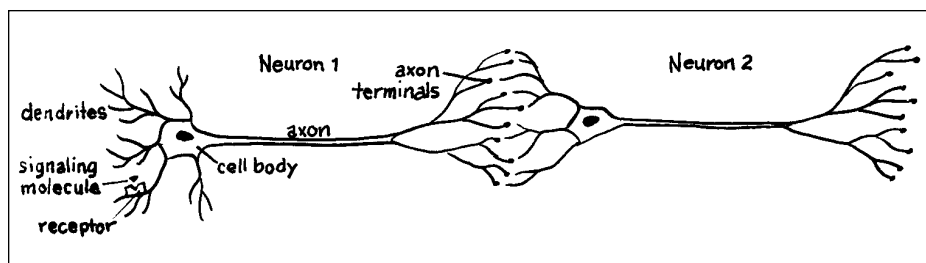
Content Standard C:

Cell functions are regulated.

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Case A

The signal molecule that affects Neuron #1 in this case is inhibitory. It reduces the chances that Neuron #1 will fire. Thus, it acts to decrease the activity of Neuron #1. If Neuron #1 is less active, it releases less neurotransmitter. Neuron #1 produces glutamate, an excitatory neurotransmitter. The decreased level of neurotransmitter release from Neuron #1 leads to a decreased level of activity of Neuron #2. If Neuron #2 is less active, it will release less dopamine.



Case	Does the signal molecule excite or inhibit Neuron #1?	Does the activity of Neuron #1 increase or decrease?	Does the amount of neurotransmitter released from Neuron #1 increase or decrease?	What is the name of the neurotransmitter released from Neuron #1?	Is the neurotransmitter released from Neuron #1 excitatory or inhibitory?	Does the activity of Neuron #2 increase or decrease?	Does the amount of dopamine released from Neuron #2 increase or decrease?
A	inhibit	↓	↓	glutamate	excitatory	↓	↓

Tip from the field test: Students sometimes became confused by the multiple neurotransmitters involved in each case. A common misconception was the same neurotransmitter that acted to stimulate or inhibit a neuron then passed through the neuron and was released from the axon terminals at the other end. Remind students what they learned in Activity 2 regarding the fate of a neurotransmitter after it binds to, and then comes off of, its receptor. The released neurotransmitter is either degraded or taken back up into the axon terminal that released it.

For the purpose of this activity, the signal molecule is a neurotransmitter. In Lesson 3, students will learn that drugs of abuse can also act in a similar way to alter neurotransmission.

- After the students have worked through the first example as a class, ask them to work in their small groups to complete the chart for Cases B-D. Students will determine how inhibitory and excitatory inputs contribute to the activity of a neuron that is part of a series.

As a student group finishes one of the cases (B-D), have a group member come to the board and fill in the blanks for that problem. When all of the groups are finished, ask the group that completed each line on the board to explain its answers to the rest of the class. If another group disagrees with the answer, have that group explain its reasoning. As a class, resolve the discrepancies and reach a consensus explanation. In this way, students practice critical thinking and communication skills.

SAMPLE ANSWERS FOR MASTER 2.8

Case A. The signaling molecule is inhibitory. Neuron #1 releases glutamate as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The inhibitory signal molecule decreases the activity of Neuron #1. If Neuron #1 is less active, it releases less neurotransmitter. Neuron #1 produces glutamate, an excitatory neurotransmitter. The decreased amount of neurotransmitter released from Neuron #1 leads to a decreased level of activity of Neuron #2. If Neuron #2 is less active, it will release less dopamine.

Case B. The signaling molecule is excitatory. Neuron #1 releases glutamate as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The excitatory signal molecule increases the activity of Neuron #1. If Neuron #1 is more active, it releases more neurotransmitter. Neuron #1 produces glutamate, an excitatory neurotransmitter. The increased amount of neurotransmitter released from Neuron #1 leads to an increase in the activity level of Neuron #2. If Neuron #2 is more active, it will release more dopamine.

Case C. The signaling molecule is inhibitory. Neuron #1 releases GABA as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The inhibitory signal molecule decreases the activity of Neuron #1. If Neuron #1 is less active, it releases less neurotransmitter. Neuron #1 produces GABA, an inhibitory neurotransmitter. The decreased amount of neurotransmitter released from Neuron #1 leads to an increase in the activity level of Neuron #2 (less GABA = less inhibition of Neuron #2). If Neuron #2 is more active, it will release more dopamine.

Case D. The signaling molecule is excitatory. Neuron #1 releases GABA as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The excitatory signal molecule increases the activity of Neuron #1. If Neuron #1 is more active, it releases more neurotransmitter. Neuron #1 produces GABA, an inhibitory neurotransmitter. The increased amount of neurotransmitter released from Neuron #1 leads to a decrease in the activity level of Neuron #2 (more GABA = stronger inhibition of Neuron #2). If Neuron #2 is less active, it will release less dopamine.



Listening to students explain their answers, defend their reasoning, and modify their responses after listening to other students explain their logic will help you assess students' understanding of neurotransmission.

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Case	Does the signal molecule excite or inhibit Neuron #1?	Does the activity of Neuron #1 increase or decrease?	Does the amount of neurotransmitter released from Neuron #1 increase or decrease?	What is the name of the neurotransmitter released from Neuron #1?	Is the neurotransmitter released from Neuron #1 excitatory or inhibitory?	Does the activity of Neuron #2 increase or decrease?	Does the amount of dopamine released from Neuron #2 increase or decrease?
A	inhibit	↓	↓	glutamate	excitatory	↓	↓
B	excite	↑	↑	glutamate	excitatory	↑	↑
C	inhibit	↓	↓	GABA	inhibitory	↑	↑
D	excite	↑	↑	GABA	inhibitory	↓	↓

4. Ask students to keep their completed worksheets, Master 2.5 and 2.8. Students will refer to these when they do activities in Lesson 3.



5. Students may continue to explore how signals from one neuron influence the target neuron by doing the CD-ROM activity, *Neurons in Series*.

To access the *Neurons in Series* activity, click on *Neurons*, *Brain Chemistry*, and *Neurotransmission* on the main menu. Then select the *Neurons in Series* option from the submenu.